CHARACTERISTIC INFLUENCE OF IMPURITIES ON THE SUPERCONDUCTING TRANSITION TEMPERATURE OF THALLIUM

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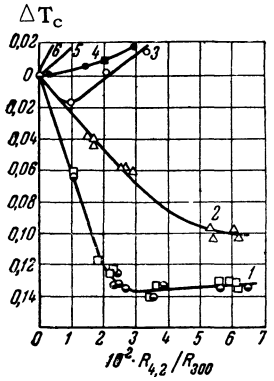
A study was made of the influence of the presence of impurity elements of various valences and various atomic radii on the temperature of the superconducting transition (T_c) of thallium. It was found that the impurities of valence lower than that of thallium (Hg, Cd) reduce T_c, while those of valence higher than that of thallium (Bi, Sb) raise it. The impurity elements having different atomic radii have different effects. Therefore, it seems that in thallium, as in other superconductors, the effect of impurities on T_c results from changes in the electron mean free path and from differences in the valences and atomic radii of the metal and impurity atoms.

SEVERAL papers have been published recently on the investigation of the effect of impurities on the superconducting transition temperature (T_c) of tin,[1] indium, aluminum,[2] and thallium.[3] For the first three metals, at low impurity concentrations, T_c decreased—as a rule—with increase of the impurity concentration.[1)] As shown by Pippard,[4] such behavior of superconductors may be due to a reduction of the mean free path of conduction electrons. It should be noted that this mechanism apparently acts only at low impurity concentrations, ($R_{4.2}/R_{300} \approx 5 \times 10^{-3}$). At sufficiently high impurity concentrations the change in T_c is governed mainly by the type of impurity (valence, atomic radius).

A completely different dependence of T_c on impurities was found for thallium. Very low concentrations of indium, lead and bismuth impurities raised the superconducting transition temperature of thallium.[3] Such behavior was associated with the special dependence of T_c of thallium on pressure.[3] Until very recently, thallium was the only metal whose T_c was known to be raised[2)] by pressure[5] (at least up to 2000 atm), and it would be interesting to establish a relationship with the effect of impurities. In our investigation, we studied the effect produced on the superconducting transition temperature of thallium by the impurity elements of valence higher than that of thallium (bismuth up to ~ 0.2 at.%, antimony up to ~ 0.4 at.%), and by elements of valence lower than that of thallium (mercury and cadmium up to ~ 1.2 at.%).



The figure shows the dependence of the shift of of the transition temperature (ΔT_c) on the residual resistance ($R_{4.2}/R_{300}$), which was used as a measure of the impurity concentration.

Curves 1, 2, and 3 present the results of our measurements for thallium with mercury, cadmium and antimony impurities, respectively.

Curves 4, 5, and 6 give the results of the measurements of Quinn and Budnick[3] for thallium containing bismuth, lead and indium as impurities; the square on curve 4 represents the result of our measurements of ΔT_c on thallium with bismuth impurity.

The figure shows that T_c of thallium decreases with increase of the concentration of an impurity

[1)] The exception is the influence of gallium impurity on T_c of indium: in this case, the transition temperature of indium increases even at the lowest concentrations of gallium.

[2)] Zirconium behaves in a similar way, as reported by N. B. Brandt and N. I. Ginzburg, on June 26, 1963, at the Tenth All-Union Conference on Low-Temperature Physics.

whose valence is lower than that of thallium. Impurities of valence higher than that of thallium (Bi, Pb, Sb), either—beginning with the lowest concentrations—raise T_c of thallium, or—after an initial reduction of T_c at very low impurity concentrations—raise T_c on further increase of this concentration (curve 3, Sb impurity). Chanin, Lynton, and Serin[2] drew attention to a similar influence of the impurity valence on T_c of indium and aluminum.

Another point should also be noted: the difference between atomic radii of impurities of the same valence affects T_c of thallium.

Thus in the case of thallium, as for other investigated superconductors, the following factors are responsible for the effect of impurities on T_c changes in the electron mean free path and differences in the valences and atomic radii of the metal and impurity atoms.

[1] Lynton, Serin, and Zucker, J. Phys. Chem. Solids **3**, 165 (1957).

[2] Chanin, Lynton, and Serin, Phys. Rev. **114**, 719 (1959).

[3] D. J. Quinn and J. I. Budnick, Phys. Rev. **123**, 466 (1961).

[4] A. B. Pippard, J. Phys. Chem. Solids **3**, 175 (1957).

[5] Kan, Lazarev, and Sudovtsov, DAN SSSR **69**, 173 (1949); Lazarev, Lazareva, and Makorov, JETP **44**, 481 (1963), Soviet Phys. JETP **17**, 328 (1963).

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